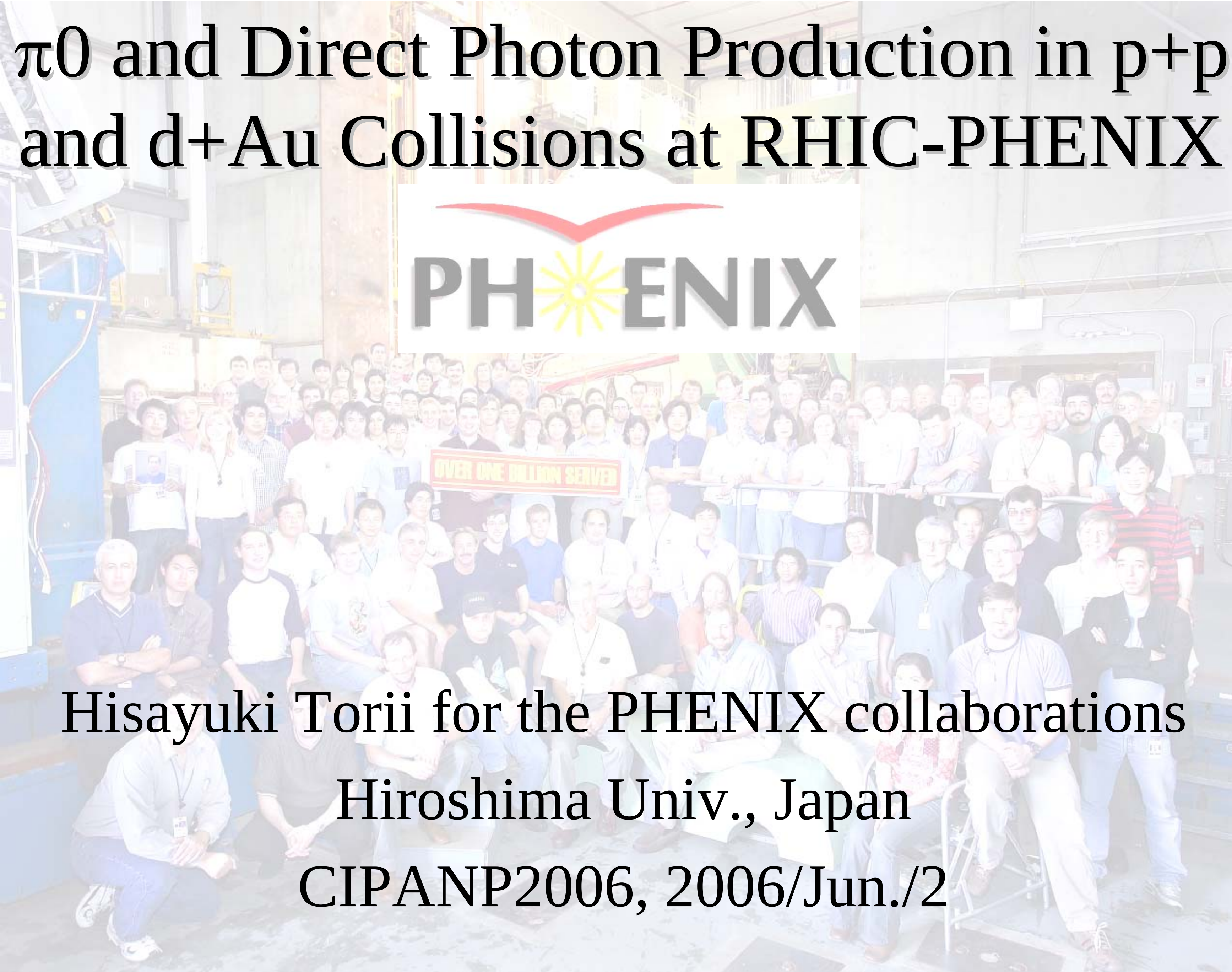
$\pi 0$ and Direct Photon Production in p+p and d+Au Collisions at RHIC-PHENIX



Hisayuki Torii for the PHENIX collaborations

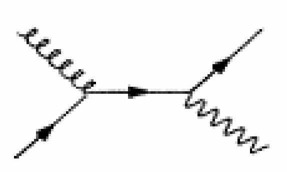
Hiroshima Univ., Japan

CIPANP2006, 2006/Jun./2

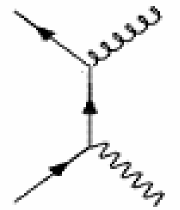
Hard Probe in p+p

- $\pi 0$ in RHIC is a good tool for gluon jet

- Photon in p+p is a good probe for the parton structure.
    - Leading process
    - Higher order
    - Bremsstrahlung Process
- Why RHIC?
    - RHIC provides the highest energy as p+p collisions.
        - Very unique
        - Less theoretical uncertainty
        - As a basic for gluon spin measurement in the future.
        - A reference for d+Au and Au+Au.

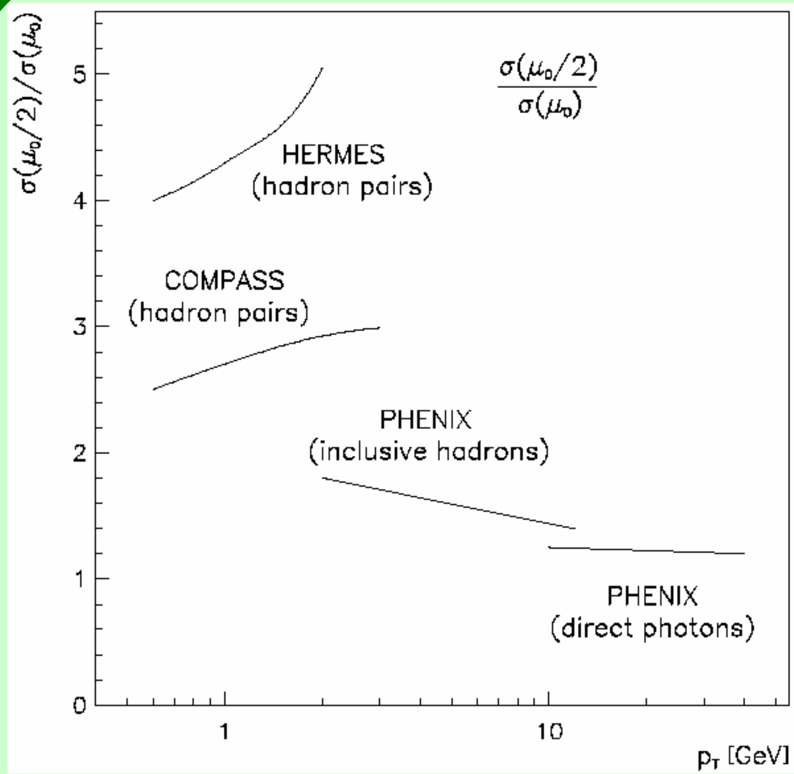


compton



annihillation

π^0 and photon in p+p is a testing ground of pQCD

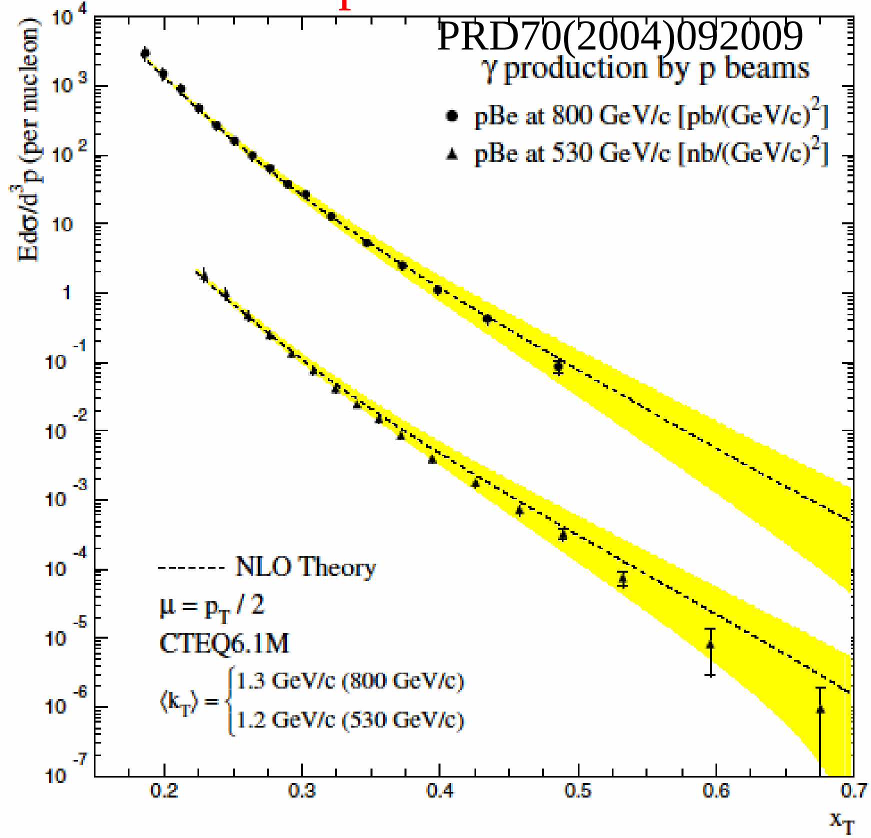


M. Stratmann and W. Vogelsang

Why d+Au?

- Nuclear Effect
  - Initial Parton Distribution
    - kT
    - (EMC effect)
    - (Shadowing, anti-shadowing)
    - (color glass condensate)
  - Final Parton Interaction
    - Multiple Scattering
    - Jet Quenching
    - ➔ Photon is less sensitive.

E706 pBe Collisions

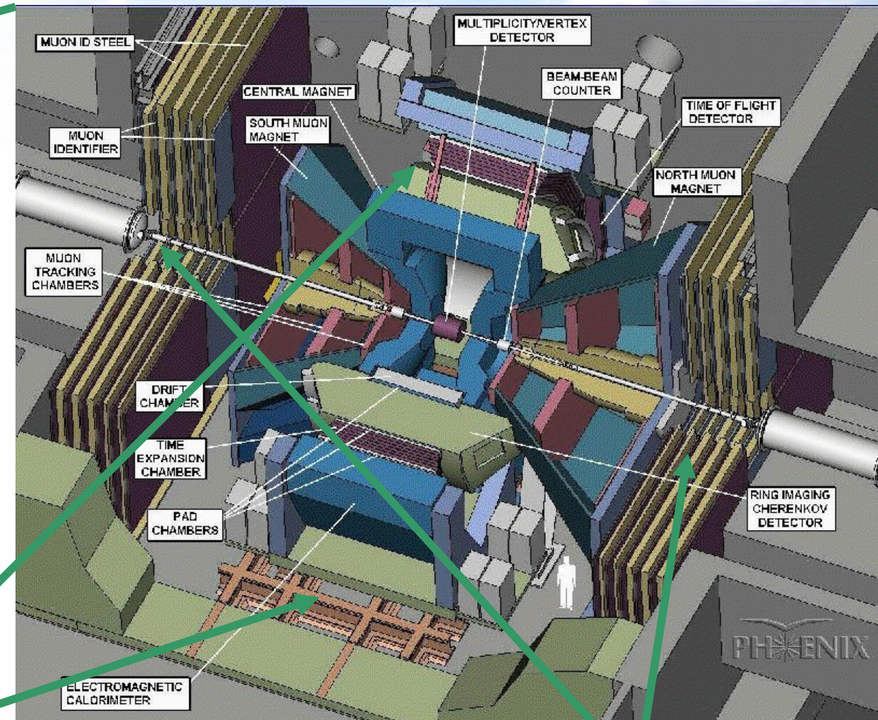


FNAL-E706 concluded
kT=~1.3GeV/c in pBe collisions

Photon in d+Au is a good probe for modification of initial distribution

PHENIX

- 3.8km with 2 rings
  - 120bunch/ring
  - 106ns crossing time
- Maximum energy
  - 250GeV for p(polarized)
  - 100GeV/nucleon for Au
- Luminosity
  - Au-Au : 2 x $10^{26}cm^{-2}s^{-2}$
  - p-p : 2 x $10^{32}cm^{-2}s^{-2}$
- 6 Crossing points



2 central Spectrometers

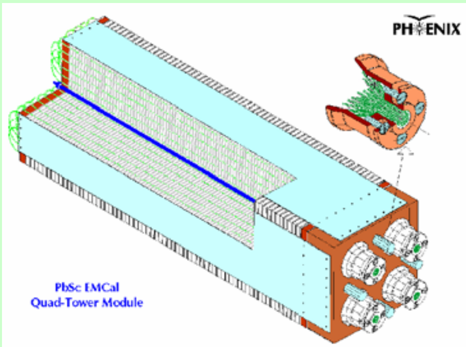
2 forward Spectrometers

- 3 detectors to measure the collision point, the luminosity, and the multiplicity.
  - Beam Beam Counter(BBC)
  - Zero Degree Calorimeter(ZDC)
  - Multiplicity and Vertex Detector(MVD)

Electro-Magnetic Calorimeter

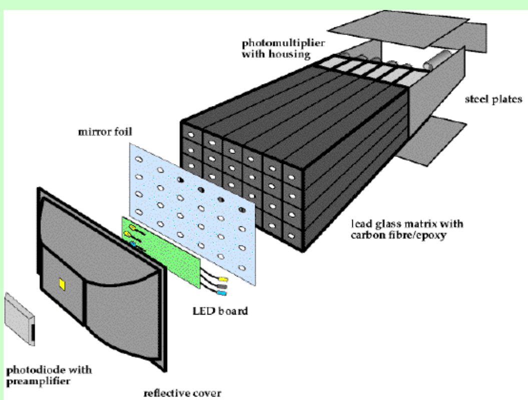
Lead Scintillator (PbSc)

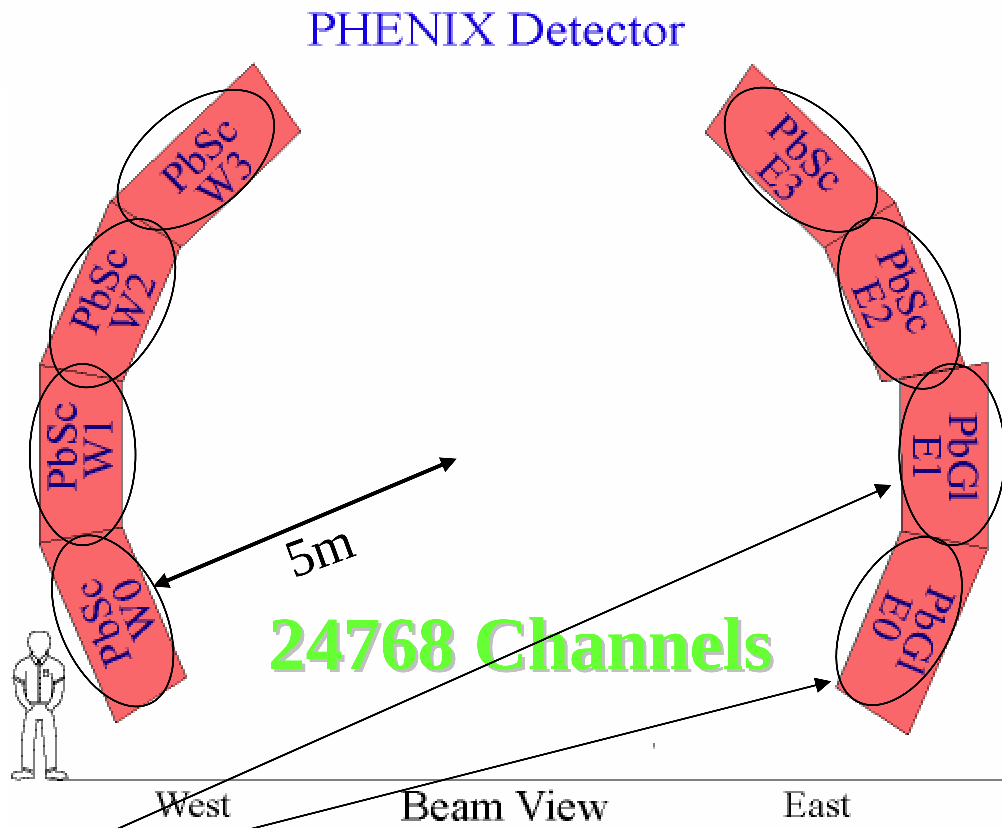
- Sandwich type calorimeter
  - Lead and scintillation plate
  - Shish-kebab type readout



Lead Glass (PbGl)

- Total reflection calorimeter





24768 Channels

Coverage $|\eta|<0.38$ $\phi = 180°$

Fine segmented calorimeter.

distinguish two photons from $\pi 0$ photons
pT~25GeV/c

History

Run	Year	Species	$s^{1/2}$ [GeV]	$\int Ldt$	N_{tot}	p-p Equivalent	Data Size
01	2000	Au+Au	130	1 μb^{-1}	10M	0.04 pb^{-1}	3 TB
02	2001/2002	Au+Au	200	24 μb^{-1}	170M	1.0 pb^{-1}	10 TB
		p+p	200	0.15 pb^{-1}	3.7G	0.15 pb^{-1}	20 TB
03	2002/2003	d+Au	200	2.74 nb^{-1}	5.5G	1.1 pb^{-1}	46 TB
		p+p	200	0.35 pb^{-1}	6.6G	0.35 pb^{-1}	35 TB
04	2003/2004	Au+Au	200	241 μb^{-1}	1.5G	10.0 pb^{-1}	270 TB
		Au+Au	62	9 μb^{-1}	58M	0.36 pb^{-1}	10 TB
		p+p	200	0.075 pb^{-1}	G	0.075 pb^{-1}	35 TB
05	2004/2005	Cu+Cu	200	15.16 nb^{-1}	G	pb^{-1}	TB
		Cu+Cu	62	0.52nb-1	G	pb-1	TB
		p+p	200	3.8 pb^{-1}	G	3.8 pb^{-1}	260 TB

π^0 Production in p+p

π^0 Production in p+p Collisions

Hadron production in hadron collisions (1+2→3+X)

$$\sigma_{1+2}^{3} = \sum_{i,j,k} \int dx_i dx_j dx_k \times \boxed{f_1^{k}(x_k,\mu) \cdot f_2^{j}(x_j,\mu)}$$

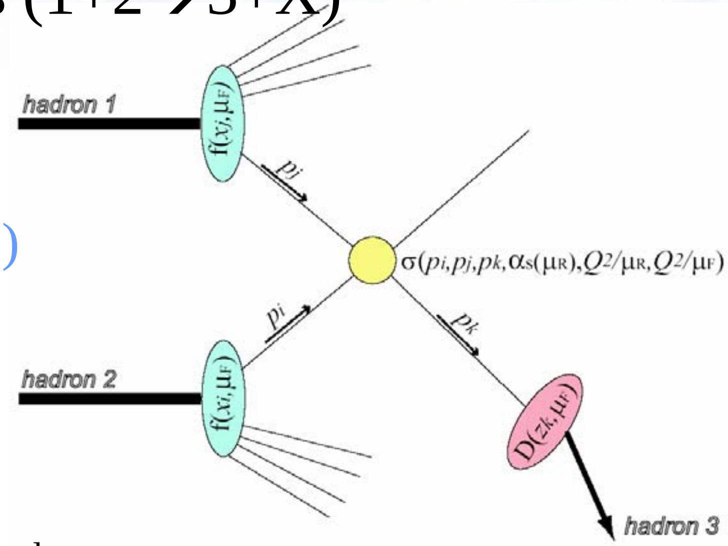
parton distribution function(PDF)

$$\times \boxed{\sigma_{i,j}^{k}\left(p_i, p_j, p_k, \alpha_s(\mu_R), Q^2/\mu_F, Q^2/\mu_F\right)}$$

$$\times \boxed{D_k^3(z_k, \mu_F)}$$

fragmentation function(FF)

μ_R=renormalization scale, μ_F=factorization scale



- Parton distribution and fragmentation function were determined from mainly deep inelastic scattering and lepton collisions.
- Several parameterizations of the PDF/FF have already existed.
  - PDF : GRV, CTEQ, MRST FF : BKK, KKP, Kretzer グループ

In this talk, we will compare our results with

NLO pQCD calculation.

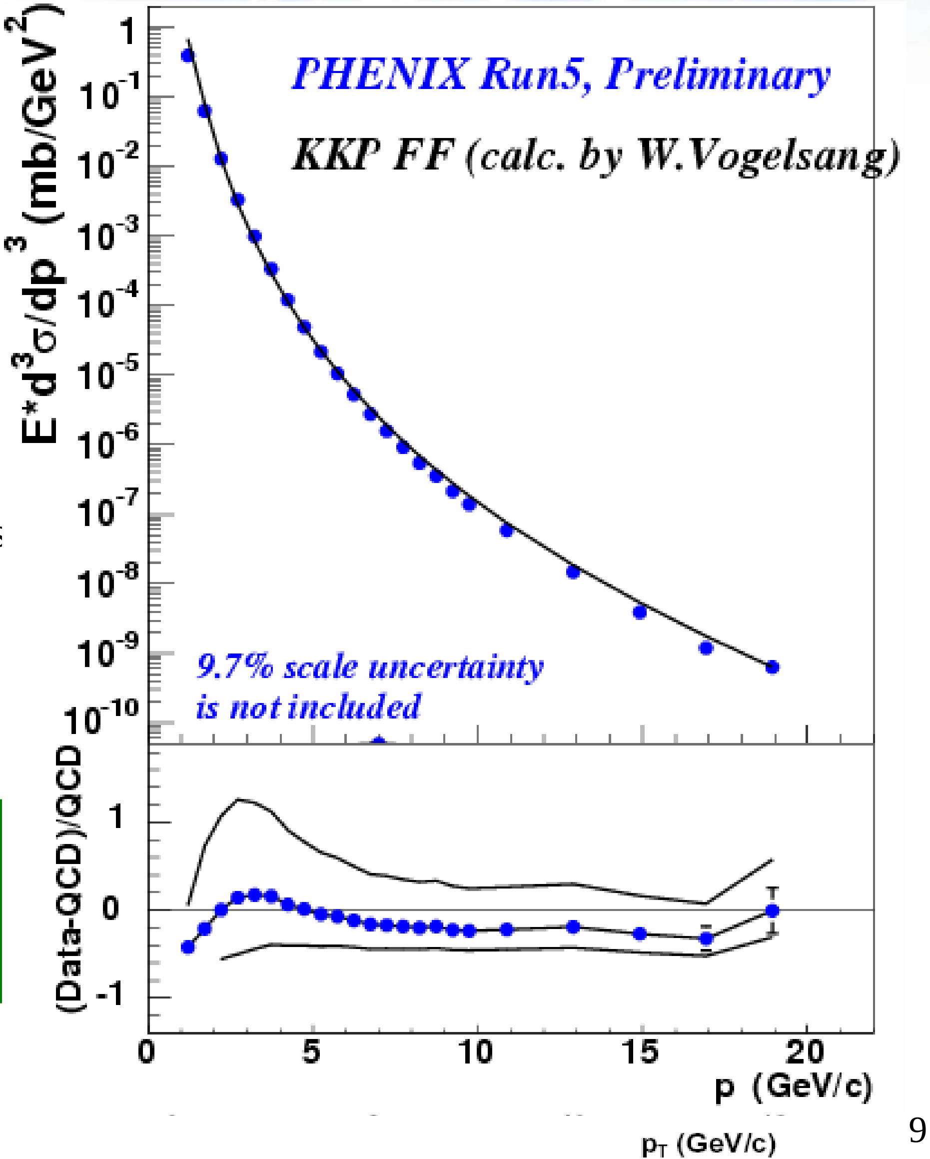
π^0's in p+p: Data vs. pQCD

- Result from run2 result
  - PRL91 (2003) 241803
- Result from run5
  - preliminary
- Comparison of π^0 cross section
  - Next-to-leading order(NLO) pQCD
    - CTEQ6M + KKP or Kretzer
    - Matrix calculation by Aversa, et. al.
    - Renormalization and factorization scales are set to be equal and set to

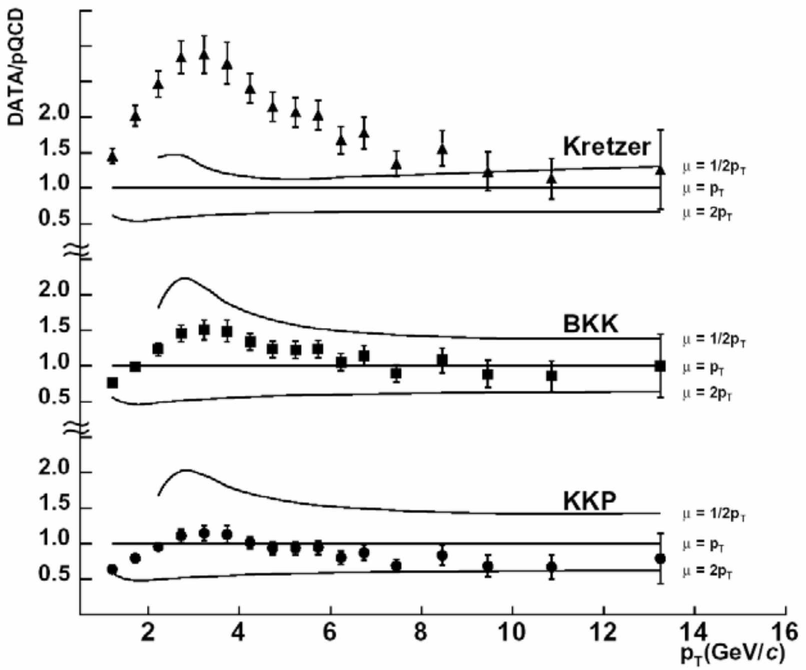
      $1/2p_T$, p_T, $2p_T$

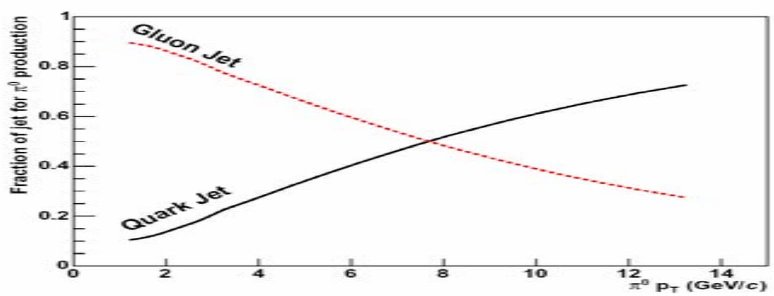
    - Calculated by W.Vogelsang

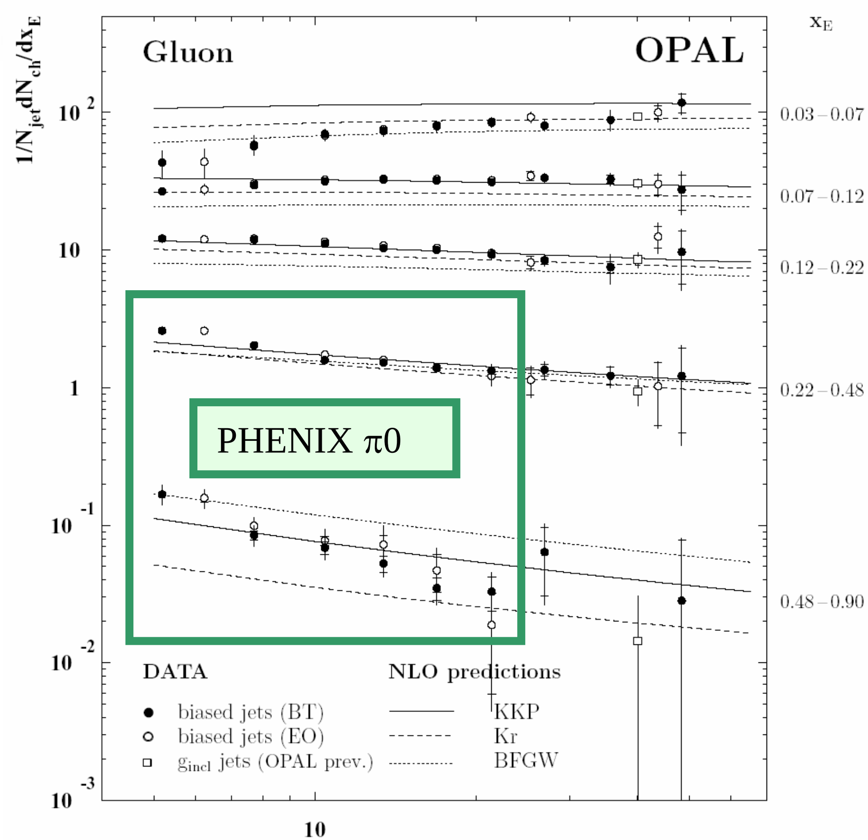
NLO-pQCD described very well down even to $p_T \sim 1$ GeV/c



Various F.F. vs. OPAL(LEP2)







E.P.J. C37(2004)25-47 hep-ex/0404026

PHENIX $\pi0$ favors KKP.

OPAL results are closer to KKP in the range for PHENIX π^0.

Direct Photon Production in p+p

Direct Photon Production

Direct photon production consists of two processes

$$\sigma = \sigma_{dir} + \sigma_{frag} = \sum_{i,j,k} \int dx_i dx_j \times \boxed{f_1^i(x_i,\mu)\cdot f_2^j(x_j,\mu)}$$

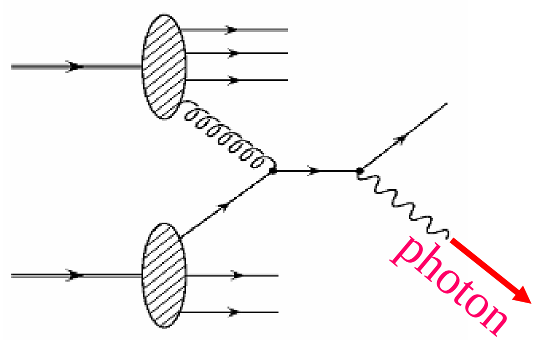
parton distribution function(PDF)

fragmentation function(FF)

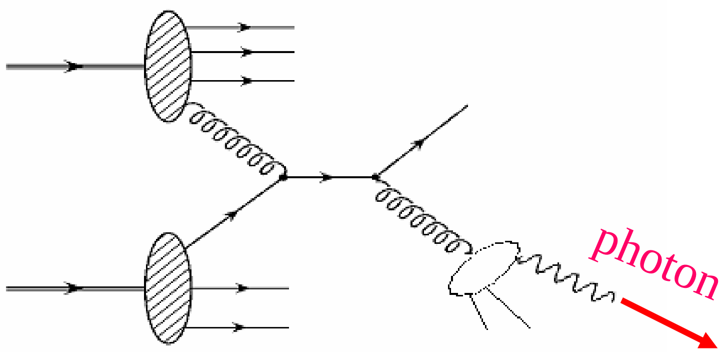
$$\times \left\{ \boxed{\sigma(i+j\to\gamma)} + \int dz \boxed{\sigma(i+j\to k)} \times \boxed{D_k^3(z_k,\mu_F)} \right\}$$

Direct Process

Bremsstrahlung Process

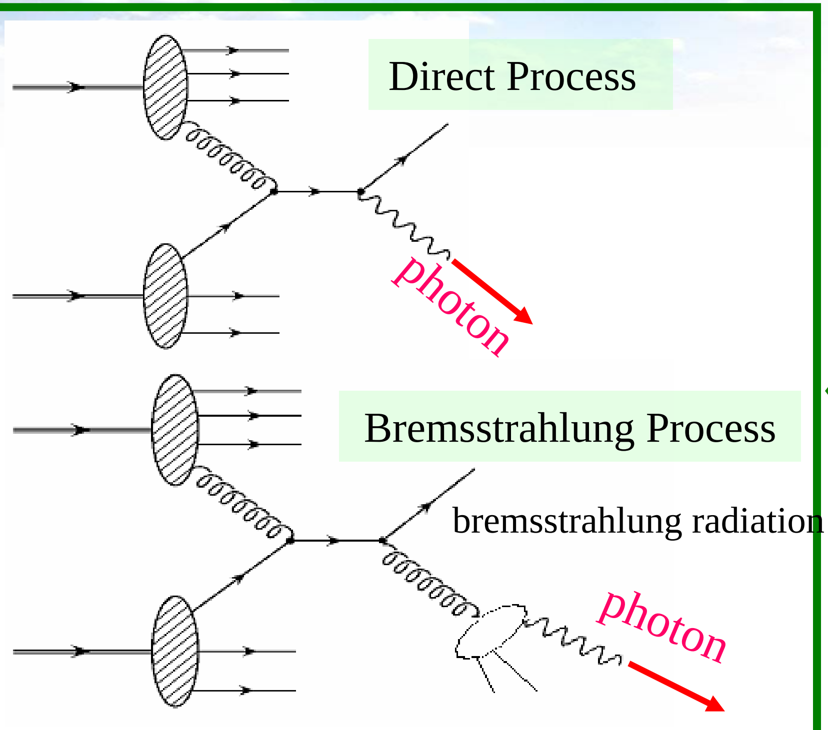


Compton/Annihilation process



In this talk, we compare our result with next-to-leading order(NLO) pQCD calculation

How to Measure?



No one know which photon from what.

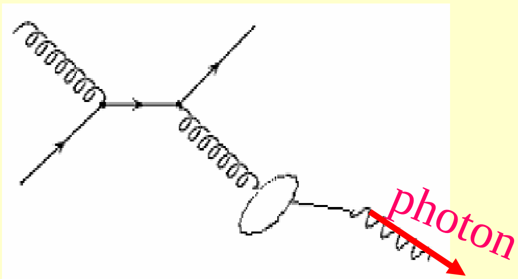
Background

Non-vertex Photon

Neutral hadron contribution

Noise in the detector

Hadron(π^0,η,ω..) decay



Estimate all backgrounds

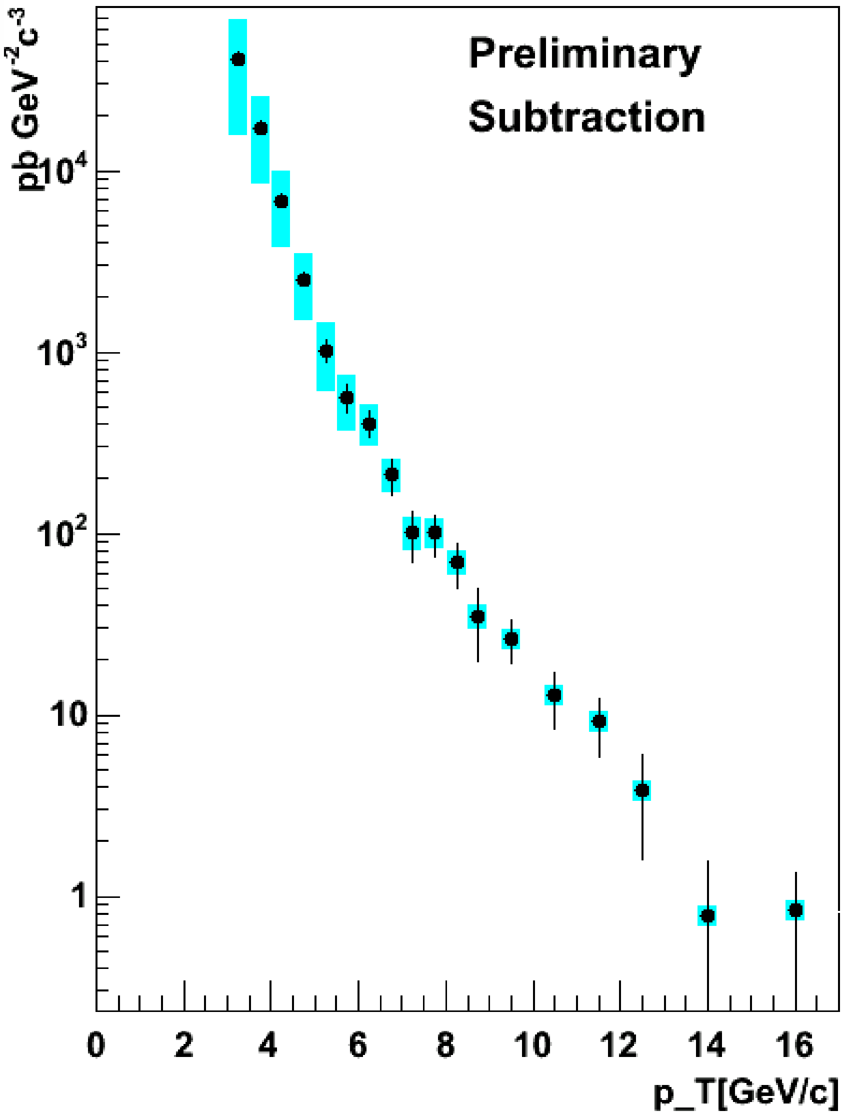
After subtracting all backgrounds,

the remained photons are the signals.

Direct Photon in p+p

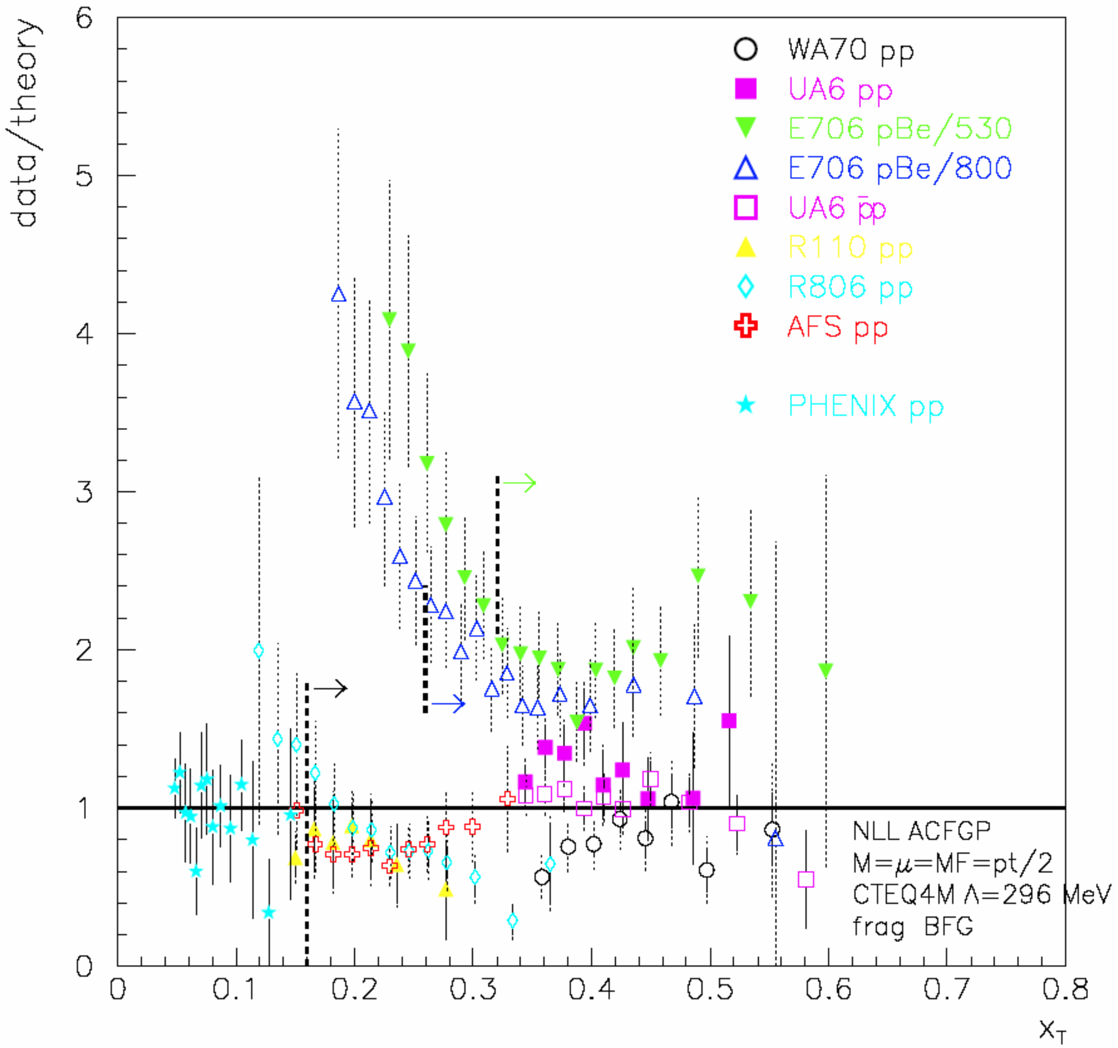
- PHENIX run3 preliminary result.
  - Recent Update down to 3GeV/c
  - Publication is coming soon.
- NLO-pQCD calculation
  - Private communication with W.Vogelsang
  - CTEQ6M PDF.
  - Sum of direct photon bremsstrhlung photon
  - 3 scales (1/2pT,1pT,2 pT)
    - For renormalization scale factorization scale

pQCD calculation can describe our result very well.



Comparison with pQCD

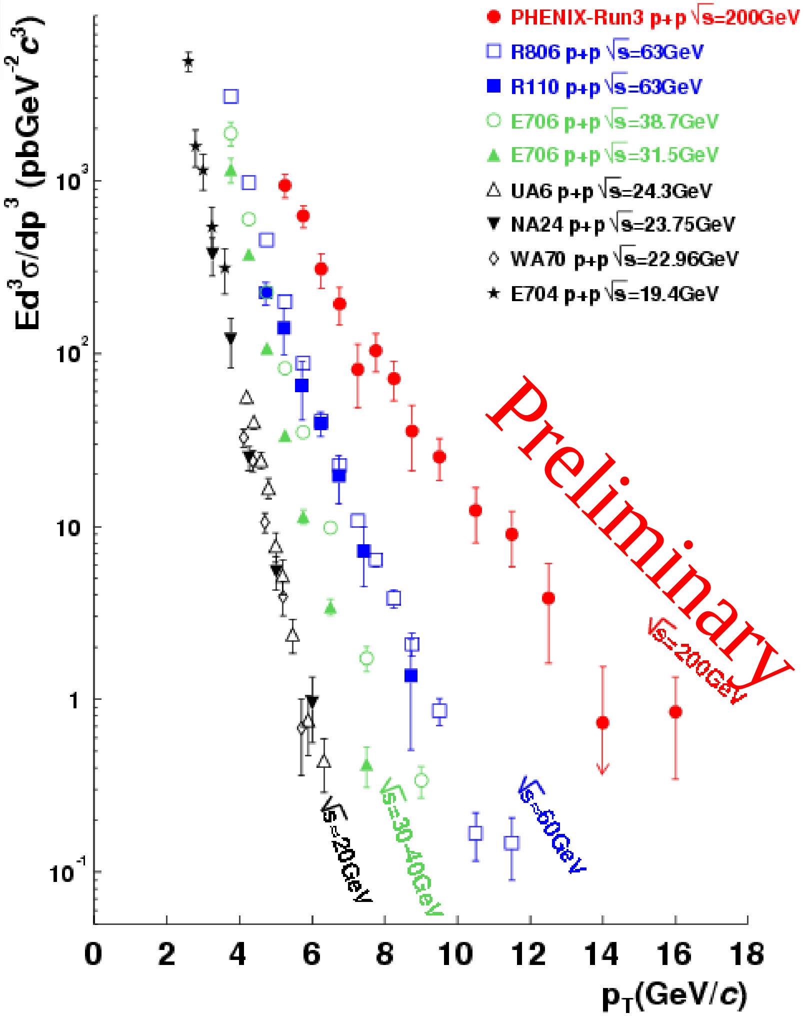
Aurenche et al Eur. Phys. JC9,10(1999)



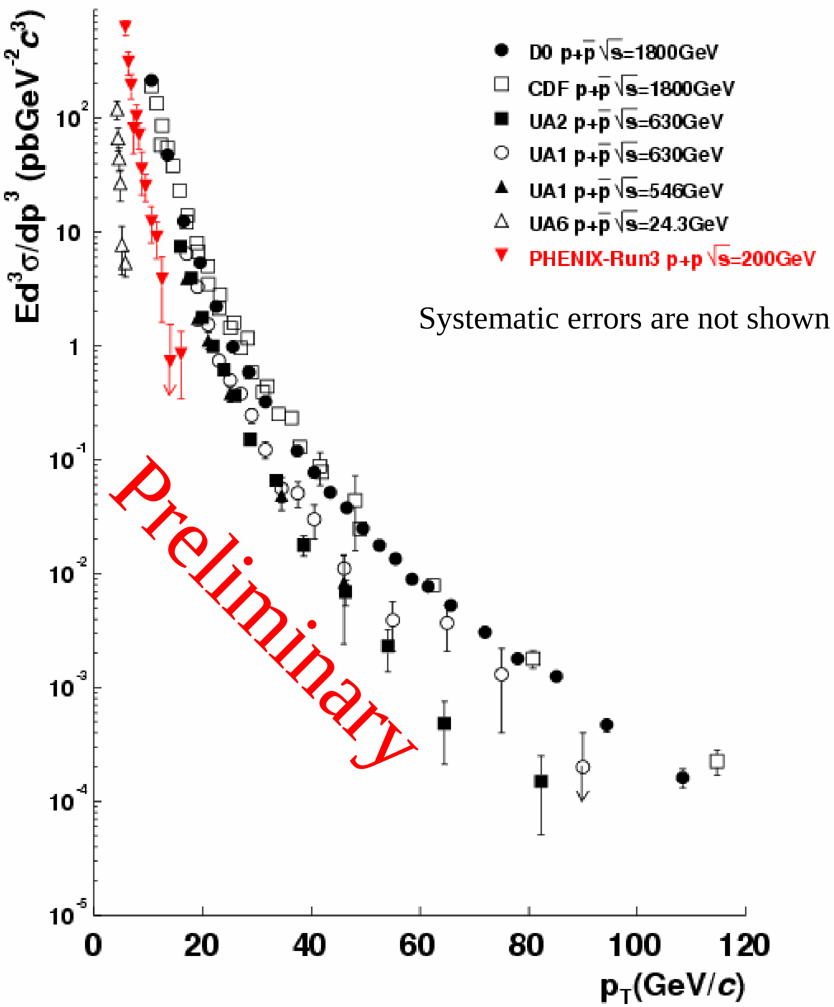
Talk by Monique Werlen at RHIC&AGS users meeting 2005

Phenix data clarifies the data/theory puzzle

Comparison with Other Experiment



proton-proton collisions



proton-antiproton collisions

x_T Scaling

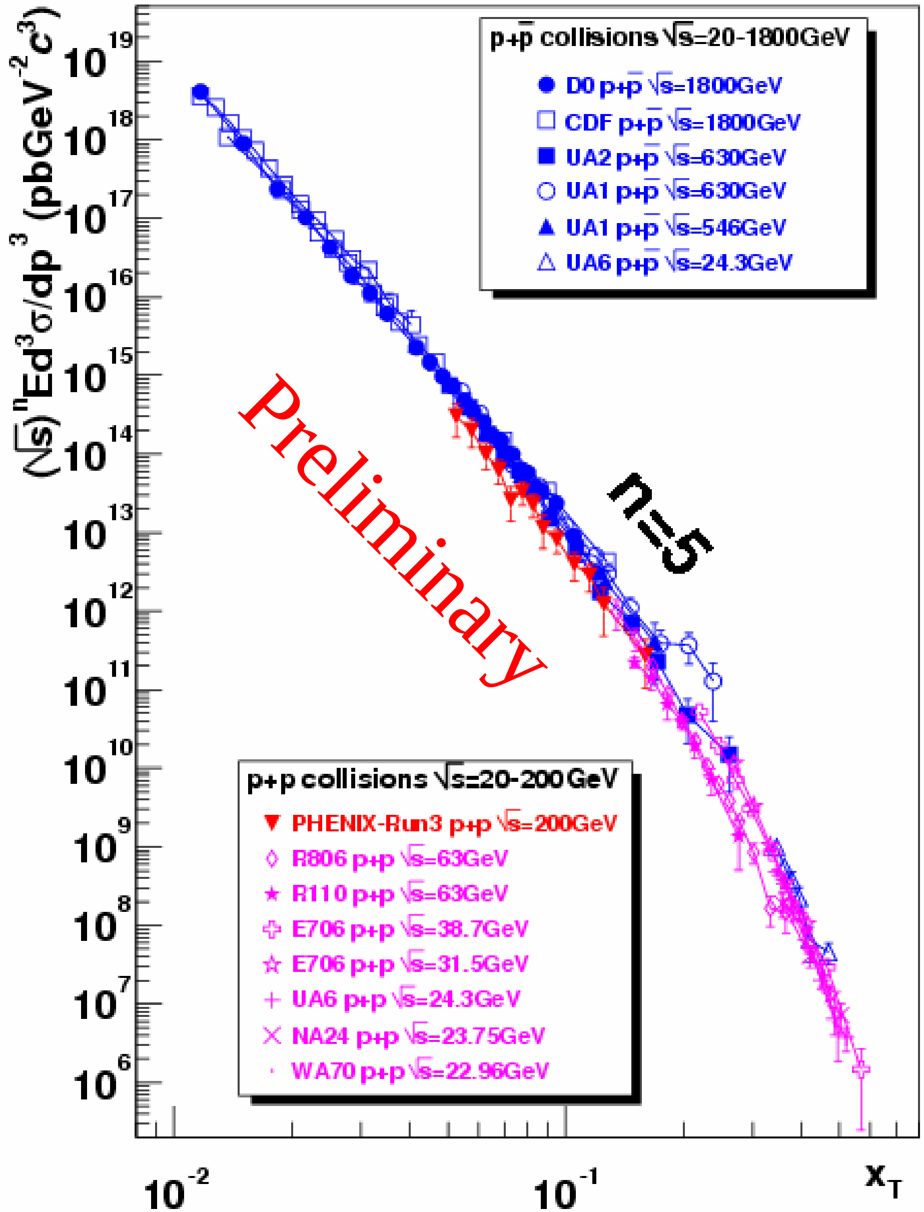
- From QCD, if
  - Q^2-Scaling of PDF,FF
  - No running coupling constant(α_s)

$$\boxed{\sigma = \left(\sqrt{s}\right)^{-n} \times F\left(x_T\right)}$$

n=constant。 $x_T=2p_T/\sqrt{s}$

  - Can be express as two terms
    - Interaction
    - Structure
  - If leading order n=4
    - Next-to-leading order: n=4+α

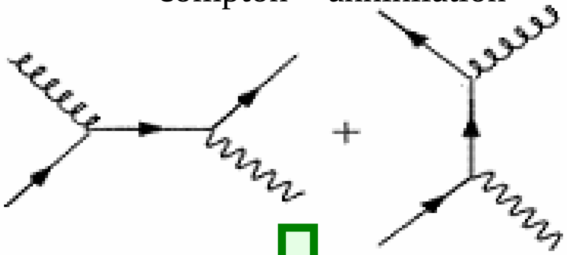
x_T-Scaling n=~5

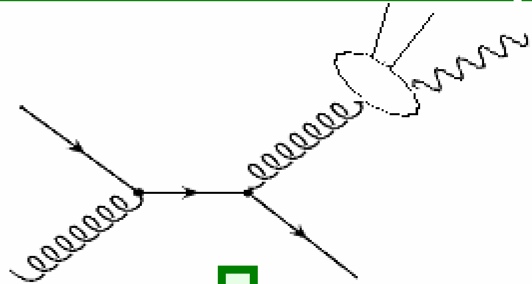


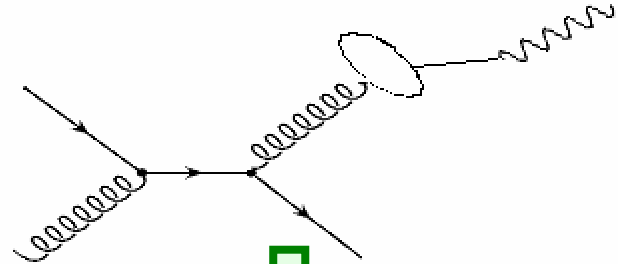
Is Photon Isolated?

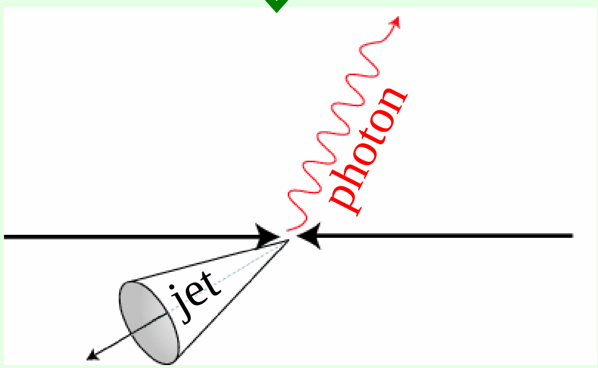
(1)Signal(direct)	(2)Signal(fragmentation)	(3)Background(hadron decay)

compton + annihilation

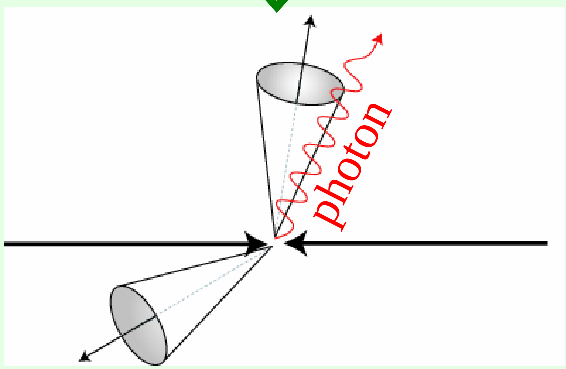




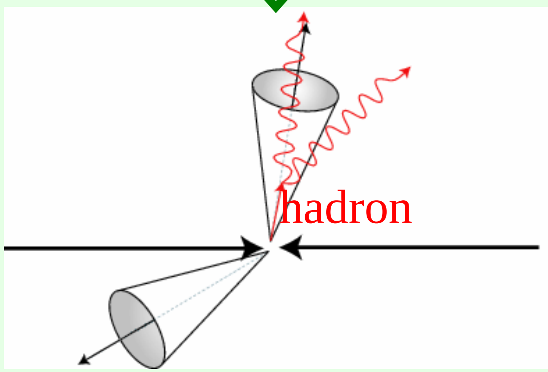




約30%@10GeV



約10%@10GeV

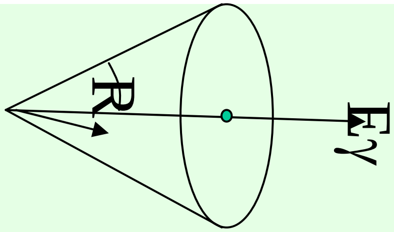


約60%@10GeV

Isolation cut to reduce background

$$R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.5$$

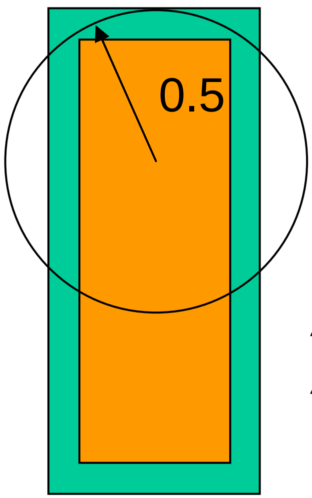
$$E_{sum}(R < 0.5) < E_\gamma \times 0.1$$



What the isolation cut

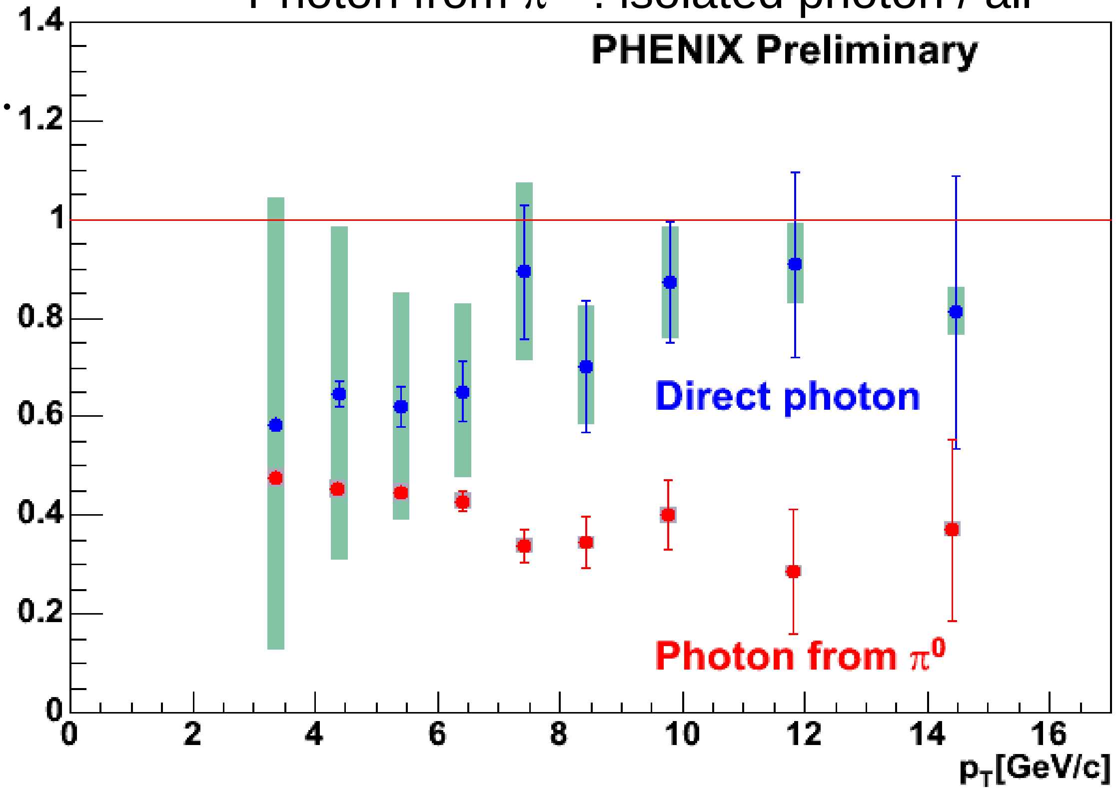
Isolated Photon/Direct Photon

PHENIX acceptance is not enough to cover 0.5 cone.



PHENIX arm
$\Delta\eta=0.7$
$\Delta\phi=\pi/2$

Direct photon : isolation / subtraction
Photon from π^0 : isolated photon / all



Photons from π0 is reduced by the isolation cut.
Direct photons are clearly isolated at high pT region.

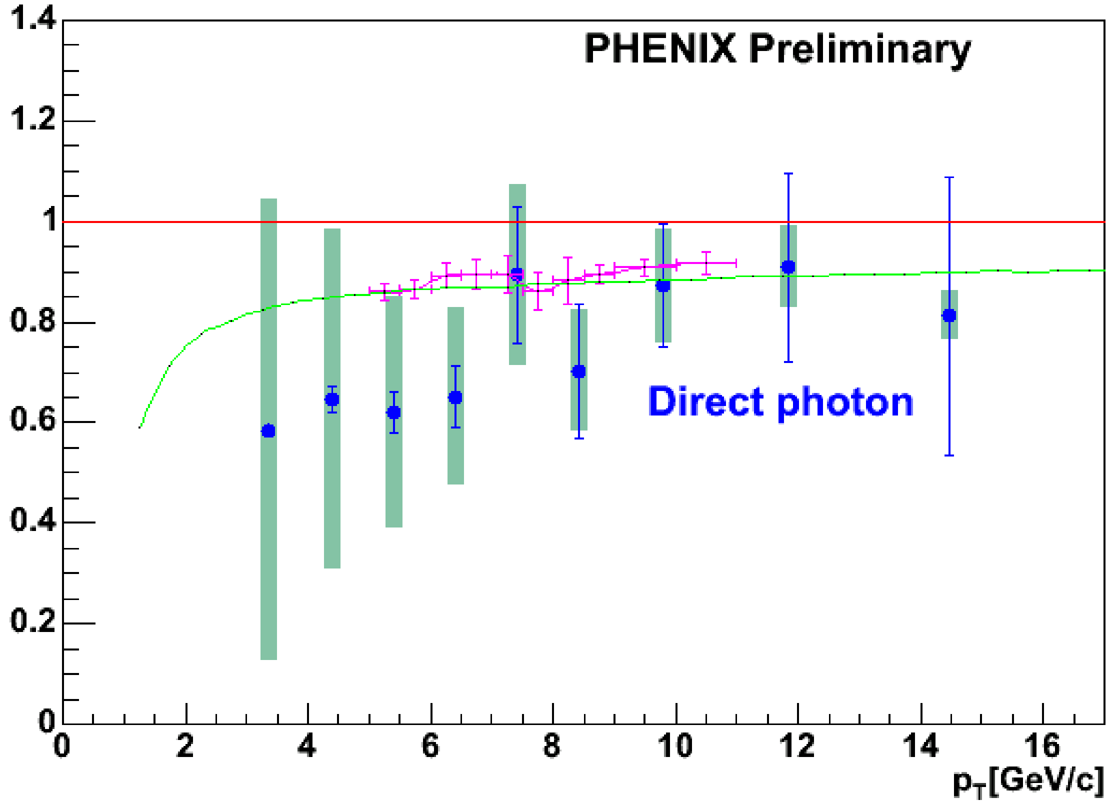
Isolation Cut vs. pQCD

Isolation cut

$0.1 * E_\gamma > E_{cone(R=0.5rad)}$

By M.Werlen,
JETPHOX
-.35<y<.35
μ=pT
BFG set2, CTEQ6M

By W.Vogelsang,
R=0.4
μ=pT, CTEQ6M



Although our systematic errors are huge,

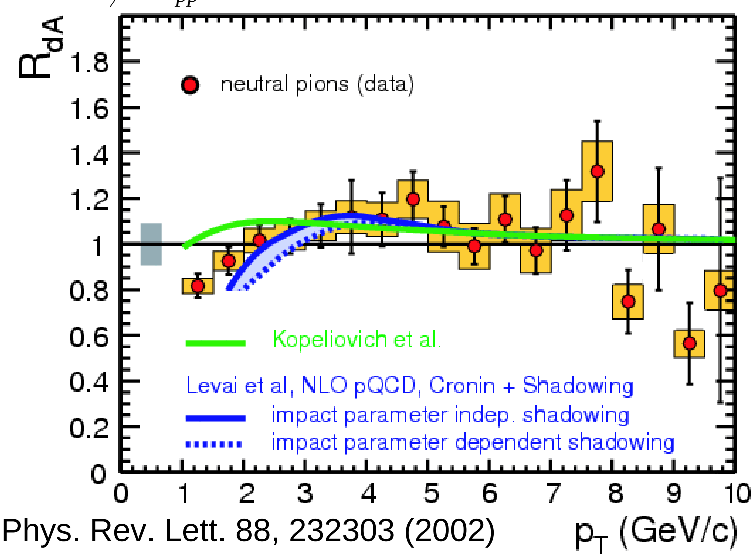
pQCD predictions (with the PHENIX isolation cut) can describe out data well.

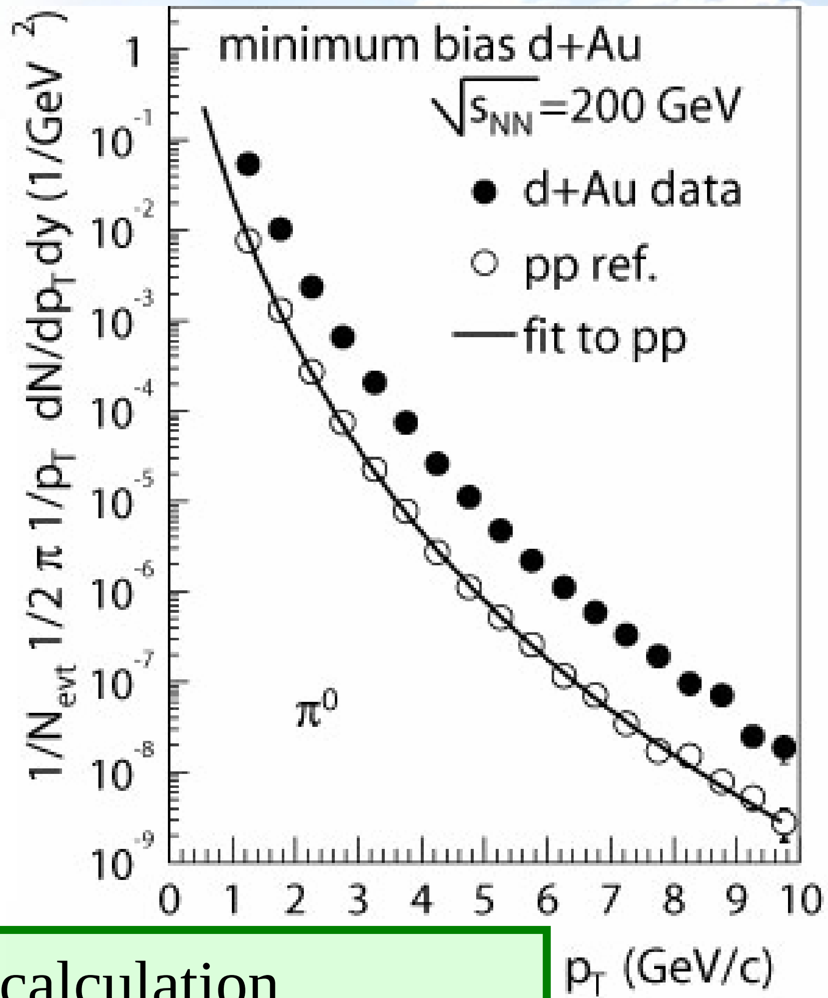
π^0 & Direct Photon Production in d+Au

π^0 in d+Au: Data vs. pQCD

- PHENIX run3 d+Au results
  - PRL91(2003)072303
- Nuclear Modification Factor

$$R_{dA} = \frac{\left[d^2N_{dA}/dp_T\,d\eta\,dN_{evt}\right]}{\left\langle N_{coll}\right\rangle \big/ \sigma_{pp}^{inel} \times \left[d^2\sigma_{pp}/dp_T\,d\eta\right]}$$

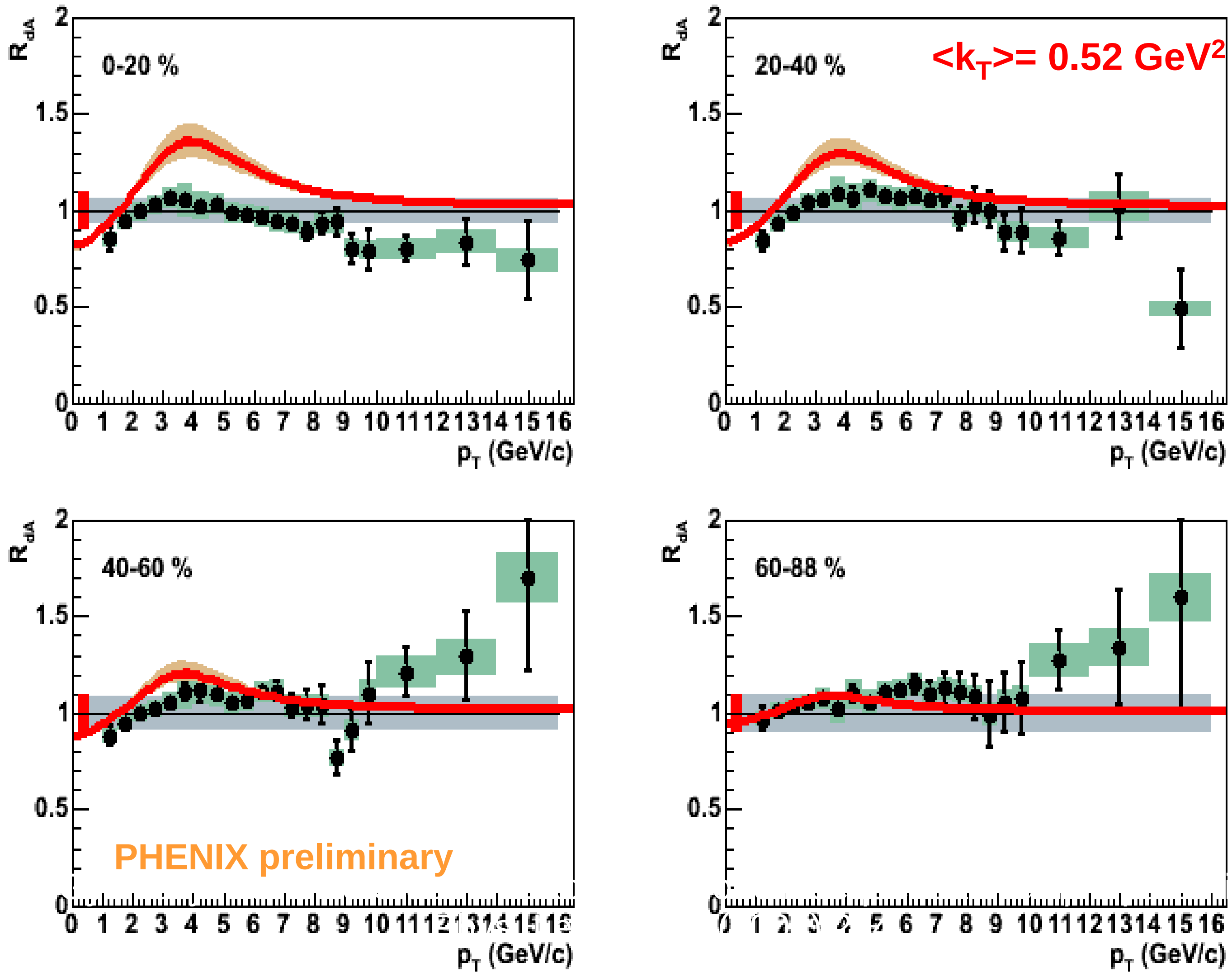




Kopeliovich et al., Phys. Rev. Lett. 88, 232303 (2002)
Levai et al., nucl-th/0306019

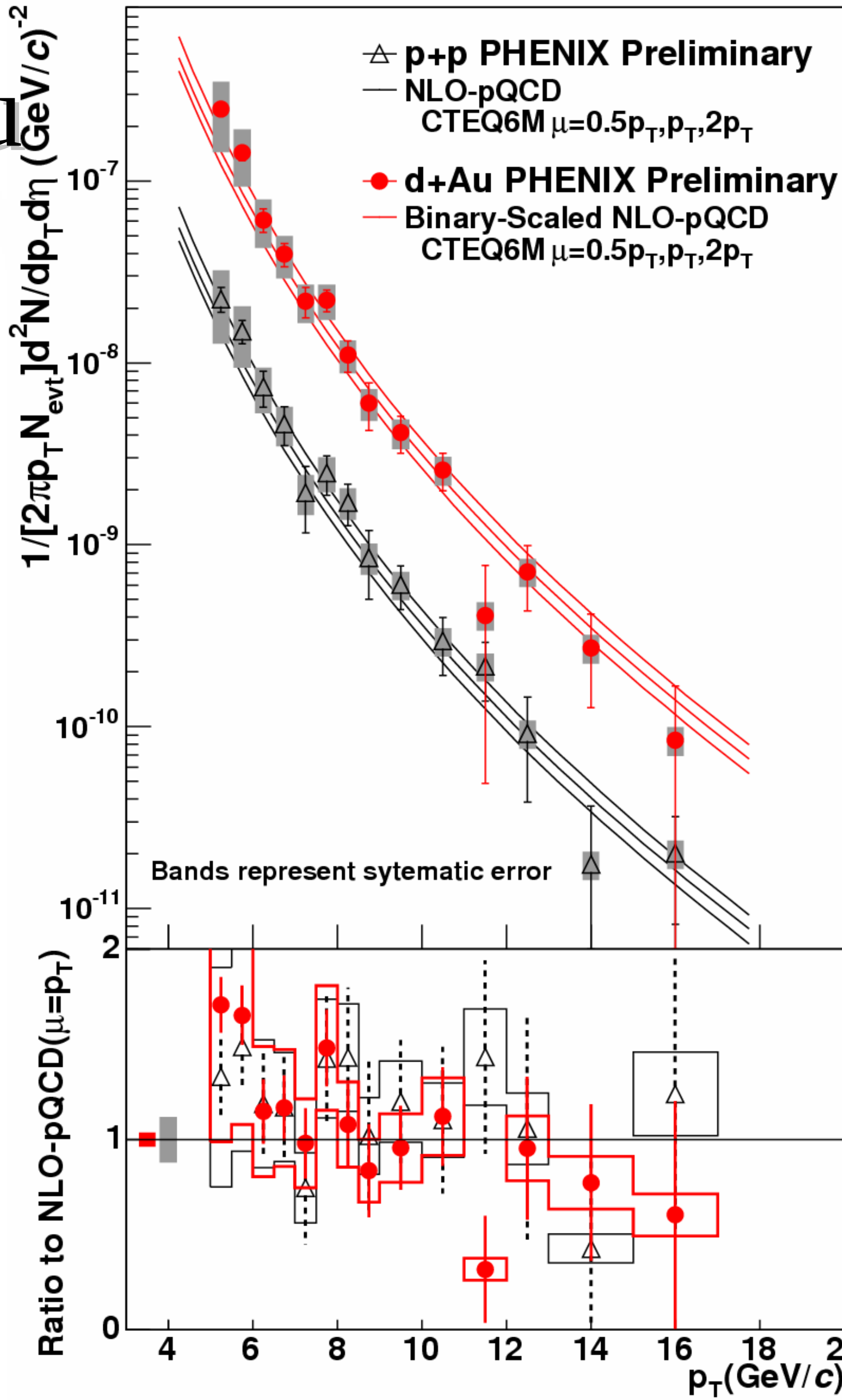
An NLO pQCD calculation
(+ phenomenological model of Cronin-Effect + Shadowing)
can describe our results

π^0 in d+Au: Centrality



Direct Photon in d+Au

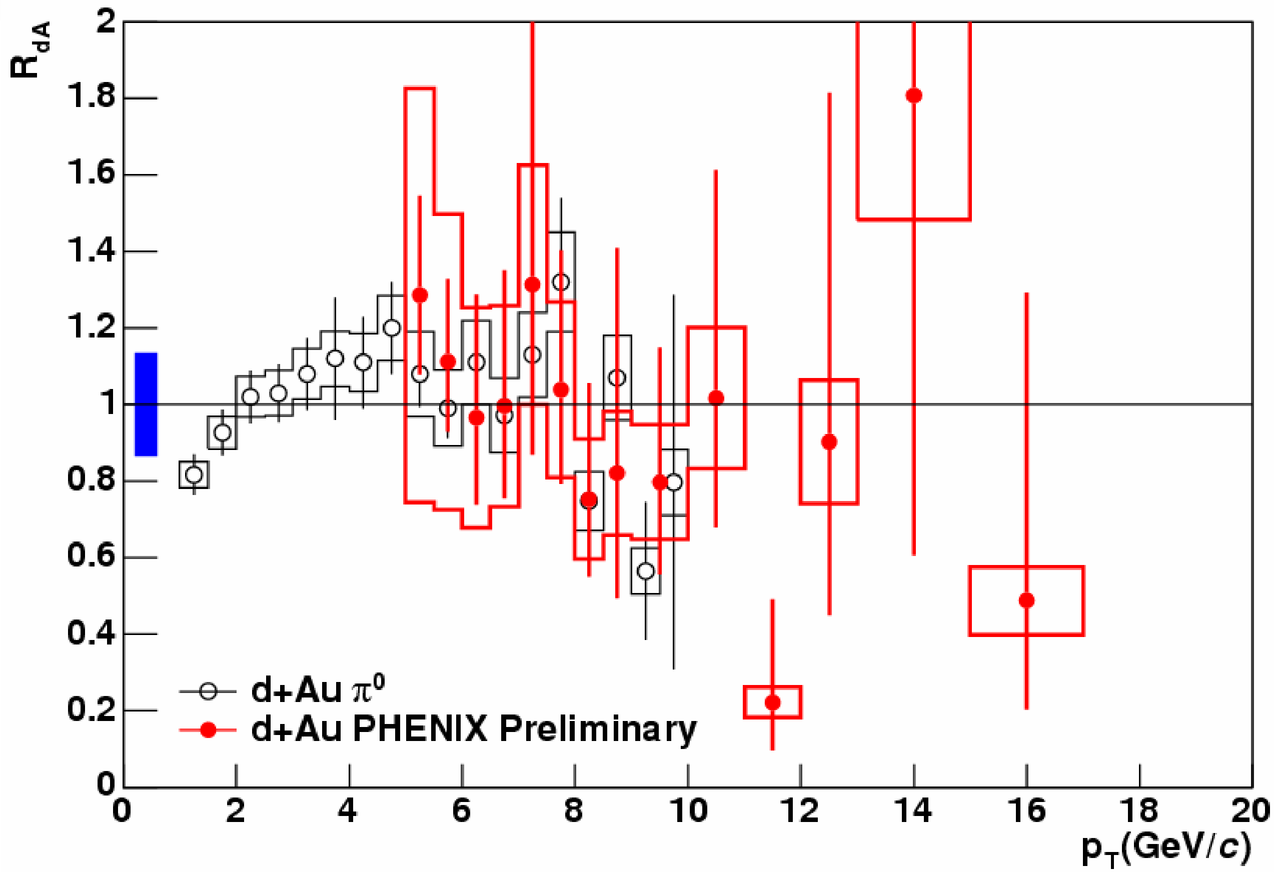
- PHENIX preliminary results
  - More data with lower pT region is under analysis.
- NLO pQCD Calculation
  - p+p collisions
  - Calculated by W.Vogelsang
  - CTEQ6M
  - Scale(renormalization and factorization scale) 0.5,1.0,2.0pT
- In comparison with d+Au
  - Averaged number of collisions (8.42) from the Glauber model was multiplied to the calculation.



Result is consistent with the binary – scaled NLO-pQCD calculation

Direct Photon in d+Au: Nuclear Modification Factor

Nuclear modification factor compared with π0 results



Consistent with 1 ➔ No modification within the error

This is consistent with what we measured in π^0

Conclusion

- p+p collisions
  - NLO pQCD calculation can describe PHENIX π^0 and direct photon.
    - PHENIX π^0 measurement gave an baseline for gluon fragmentation part.
    - For direct photon, an excess in low pT region (3-5GeV/c) is still under investigation.
  - Fit in xT scaling with other experiment
  - PHENIX isolation cut confirmed the reduction of photons from $\pi 0$.
    - Efficiency of the PHENIX isolation cut is consistent with a theory prediction.
    - Direct photon signal is isolated in high pT region.
- d+Au collisions
  - comparison with NLO-pQCD
    - π^0 result is consistent with the binary-scaled NLO-pQCD calculation + Cronin effect + shadowing.
    - Direct photon result is also consistent with the binary-scaled NLO-pQCD calculation although the systematic and statistic errors are larger than that in π^0.
      - Result is consistent with $\pi 0$